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Proposed Topic of Research

Dielectric Constant Engineering For Improvements in Performance Of MS Antenna.

Objective of the Proposed Research

The proposed study is intended to the following objectives:

1. The effect of cavity size on shift in resonance frequency of the MS Antenna. High Frequency Structure Simulator (HFSS) software will used for simulations.
2. Three different dielectric materials will be investigated for several resonance frequencies.
3. Variation of f/f_0 with Area Ratio (AR) will be studied to generalize the result. Area Ratio is the ratio of area of cavity to the area of the patch. (Area of the cavity surface below the patch is referred to as cavity area for the sake of brevity). For all ε and all f/f_0 the curve will be described by an equation.
4. A mathematical formula that relates the resonance frequency with dimensions of the cavity will be derived.

Background of the Proposed Research

Dielectric Constant Engineering (DCE) has emerged as a new tool for manipulating the characteristics of micro-strip antenna (MSA). When a patch antenna is fabricated, size of the fabricated resonance patch may be slightly different from its designed value due to tolerances in the fabrication operation. This will alter the resonance frequency. To overcome this problem, this research proposal presents a new method for fine tuning of resonance frequency by using Dielectric Constant Engineering. This approach is especially suited to LTCC and similar processes, where the antenna dielectric is composed of several layers. Composite dielectric constant of the multilayer structure is modified in such a way that the resonance frequency is set back to the designed value. This DCE is done by cutting a cavity below the patch in one or more dielectric layers. This research proposal investigates the effect of cavity size on shift in resonance frequency of the MS Antenna. High Frequency Structure Simulator (HFSS) software will used for simulations. Three different dielectric materials will be investigated for several resonance frequencies. Variation of f/f_0 with Area Ratio (AR) will be studied to generalize the result. Area Ratio is the ratio of area of cavity to the area of the patch. (Area of the cavity surface below the patch is referred to as cavity area for the sake of brevity). f is the resonance frequency for a given cavity area and f_0 is its value without any cavity. Depth of the cavity may be equal to either one or two dielectric layer thickness in a 4 layered dielectric structure.. For all ε and all f/f_0 the curve can be described by an equation.

INTRODUCTION

The general study of Dielectric Constant Engineering for improvements in performance of MS antenna covers wide range of descriptions. Firstly it is necessary to understand the theory of dielectric constant engineering, it is necessary to be equipped with the basic knowledge of effective dielectric constant. Since the effective dielectric constant provides some important properties of MS antenna like characteristic impedance, resonance frequency etc, so it can be used as a key parameter of any research related to MS antenna.

The effective dielectric constant controls the resonance of the antenna. The difference between dielectric constant and the effective dielectric constant is that the dielectric constant is a bulk material property of homogeneous material and effective dielectric constant is the

equivalent dielectric constant of inhomogeneous material. Dielectric constant engineering means applying any technique for modification in effective dielectric constant. Those changes also give impact on performance parameters of MS antenna. The modification in effective dielectric constant can be performed by any method. In this work the multilayered dielectric structure will be considered and physical change in material of substrate will be done for modification in effective dielectric constant.

Secondly it is necessary to understand the operation of MS antenna which involves the theory of MS antenna. Antennas play a very important role in the field of wireless communication. Some of them are Parabolic Reflectors, Patch Antennas, Slot Antennas, and Folded Dipole Antennas. Each type of antenna is good in its own properties and usage. A Micro-strip patch antenna is very simple in construction. Most commonly used Micro-strip patch antennas are rectangular and circular patch antennas. These patch antennas are used in simple, as well as widest and most demanding applications. In today's technologies basic structure of Micro-strip Antenna may include several dielectric layers. Effective dielectric constant, ε_{eff} , of such a multilayer dielectric structure will depend on the geometry of the structure.

Thirdly in order to understand the improvements in performance parameters of MS antenna it is necessary to know all about these parameters. The area of knowledge of all performance parameter is very vast, so in this dissertation only resonance frequency will be considered for improvement. The modification in effective dielectric constant by changing the physical material of substrate will be done for improvement in resonance frequency. That's why this dissertation will be named as dielectric constant engineering for improvements in performance parameter (resonance frequency) of MS antenna.

This work will involved the well known relation of dielectric constant(ε_o) and resonance frequency (f_0) for improvement in one parameter by changing other parameter. The relation will be defined below

$$f_0 = \frac{c}{2(L + \Delta L)\sqrt{\varepsilon_0}}$$

The simulation results of the different structures having change in dielectric material by inserting a cavity below the patch will be investigated for improvement in resonance frequency.

Scope of the work: - The Scope of the work is to study the concept of dielectric constant engineering for improvement in performance of MS antenna. During the design process the frequency of operation, polarization, impedance, radiation pattern, gain and bandwidth are the parameters which describe the performance of antenna and are called as performance parameters. The designer must consider these design parameters and should be able to adjust these as needed.

In this work the antenna will consider as multilayered and the dielectric constant will modify by changing the physical material of substrate. This change will give the improvement in performance parameters. In this work will focus only on the resonance frequency because it directly affects the propagation of wave of MS antenna. Calculation of the resonant frequency by modifying the dielectric constant of multilayer rectangular patch antenna will be studied. The simulations will be done by using HFSS. Then, the comparison between calculation and simulation will be investigated. The calculation will be done at frequency 2.4 GHz with dielectric constant 4.4. Then, the antenna will be designed at 1.6 GHz, 1.8 GHz with different dielectric constant 4.4, 2.2 and 3. The performance parameter of the antenna (resonance frequency) will be formularized with the dimension of air-cavity. From this work the resonance frequency of any designed antenna would be tuned simply by modifying the effective dielectric constant of the substrate material by cutting the material from dielectric layers

Literature Review of Research Topic :

Microwave integrated circuit technology has developed very rapidly due to its numerous unique and attractive features. For good design of microwave integrated circuits, accurate value of dielectric constant must be known. This dissertation is concerned with the dielectric constant engineering for improvement in performance parameter of MS antenna. The resonance frequency will be considered as a performance parameter in this dissertation. Due to multilayer dielectric structure and for dielectric constant engineering a term effective composite dielectric constant will be used. Here the effective dielectric constant means the aggregate dielectric constant of multilayer structure including Air-cavity. One of the objectives of this dissertation is to find out a simple method of calculating the effective dielectric constant (ε_{eff}). For finding the easy method to calculate the effective dielectric constant the literatures related to multilayered dielectric structure and methods of calculating composite dielectric constant will be studied. The summary about that literature has described below.

Different methods are available for measurement of dielectric constant of material at microwave frequencies. One very common technique is the use of waveguide cavities which are partially or completely filled with the dielectric material to be measured. Another technique is the strip line method in which dielectric material is used as dielectric filling material in the tri plate-type strip lines [l]. Napoli & Huges [2] reported a typical method for measuring dielectric properties of substrate material. They measured the resonance characteristics of a parallel plate resonator using the dielectric material. Itoh [3] measured the dielectric properties of slab type material using a micro strip cavity loaded with the slab of material- under- test. D. Shimin [4] presented an iteration method to compute the dielectric constant of the substrate from the knowledge of resonance frequency and input impedance of rectangular patch antenna. Ranjit singh [5] described a simple nondestructive method for the measurement of dielectric constant of slab type materials. The experimental procedure is very simple and consists of measuring only the resonance frequency of micro-strip patch radiator of any shape. Simple formula will be developed for the dielectric constant of the material. It also tells about the uncertainty of the dielectric constant value. But Ranjit Singh's paper does not suggest any formula to calculate the dielectric constant of multilayer dielectric structure

also this paper does not consider the effect of change in value of resonance frequency due to fabrication error. It can be say that the scope of this Ranjit singh's paper is only the single layered structure and the formula for effective dielectric constant of that. It does not consider the performance parameters.

In literature, the analytical formula for ε_{eff} is complicated [6, 7]. However, Jansen [8] showed a spectral domain technique for calculating ε_{eff}. Jansen's results implied that a consideration of any thin material on a substrate must be taken into account for evaluation of the effective dielectric constant. Quasi-TEM assumption will be used in these calculations [9]. Furthermore, superposition of partial capacitance will be applied to the analysis for co-planar wave guide by Veyers experimentally [10]. Yeong J. Yoon derived a simple and accurate formula for effective dielectric constant based on the quasi-TEM assumption and superposition of partial capacitance. That is

$$\varepsilon_{eq} = \frac{d_1 + d_2}{\frac{d_1}{\varepsilon_{r_1}} + \frac{d_2}{\varepsilon_{r_2}}}$$

Where ε_{r1} and ε_{r2} are the relative dielectric constant of the two layers.d_1 and d_2 are the distances between the boundaries.

But the Yeong J. Yoon's paper does not specify what will be the effect on resonance frequency if there is any change in multilayer dielectric material. Of course this paper have not need of it. But the work will be related to our investigation needs that.

All literatures summarized above, just help us to understand the behavior of multilayered dielectric structure and some methods for calculating effective dielectric constant that of course sketch the base of our work but does not contain any matter to follow directly.

This proposal will be reported a new method for calculating the resonance frequency by modifying dielectric material by inserting the air-cavity in multilayered dielectric structure.

The part of literature survey has also been necessarily included the theory of micro-strip antenna because it will be covered the basic information to which all should known before do the work related to MS antenna.

Theory of Micro-strip antenna

The micro-strip antenna is "an antenna that consists of thin metallic conductor bonded to a thin grounded dielectric substrate". The radiation of micro-strip antenna is based on the discontinuities of the antenna element but may also occur from bends of the antenna element. The radiation characteristics of a rectangle micro-strip antenna can be estimated from the field distribution of the patch.

A Micro-strip patch antenna (Fig2.1) is very simple in construction. Most commonly used Micro-strip patch antennas are rectangular and circular patch antennas. These patch antennas are used in simple, as well as widest and most demanding applications.

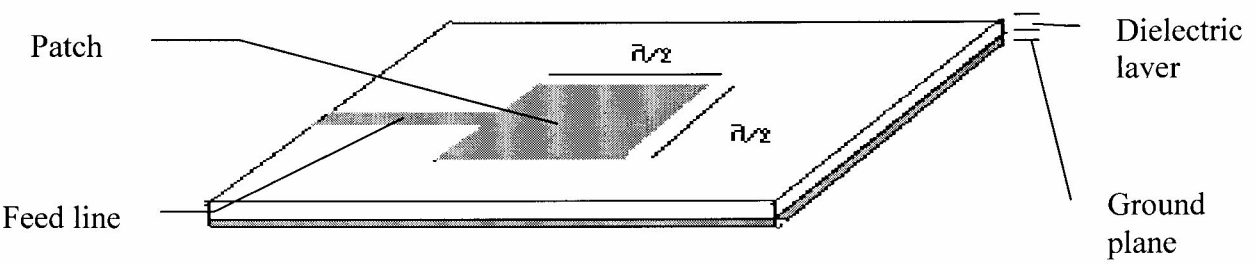
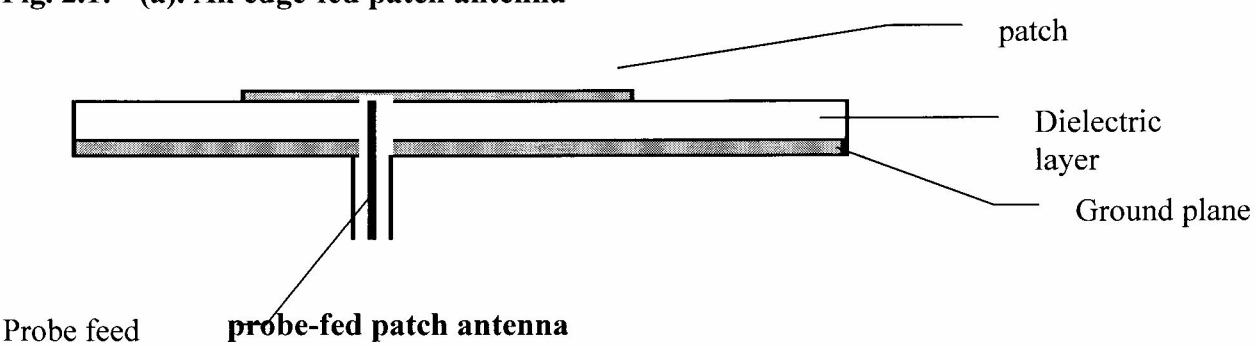


Fig. 2.1: - (a). An edge-fed patch antenna



probe-fed patch antenna

Micro-strip antennas have some merits and some de-merits.

Merits:

- Low weight, low volume and thin profile.

- Low fabrication cost, easily mass producible.

- Require no cavity backing.

- Linear and circular polarizations are possible.

- Easily integrated with microwave integrated circuits.

- Capable of dual and triple frequency operations.

- Feed lines and matching networks can be fabricated simultaneously.

De Merits:

Micro-strip antennas have some demerits:

- Low efficiency.

- Low Gain.

- Large ohmic loss in the feed structure of arrays.

- Poor end- fire radiator, except tapered slot antennas,

- Extraneous radiation from feeds and junctions.

- Low power handling capacity.

- Excitation of surface waves.

- Polarization purity is difficult to achieve.

- Complex feed structures require high performance arrays.

- Unacceptably high levels of cross polarization and mutual coupling within the array environment at high frequencies.

Types of Micro-strip Antennas:

There are different types of Micro-strip antennas which are classified based on their physical parameters. These different types of antennas have many shapes and dimensions. Micro-strip antennas can be classified in into four groups :

- Micro-strip patch antennas

- Micro-strip dipoles

- Printed slot antennas

- Micro-strip traveling wave antennas

In this dissertation micro-strip patch antenna will be considered as a base of work the investigations use formulae related to micro-strip patch antenna. So here only micro-strip patch antenna would be discussed in detail. Micro-strip, slot and dipole antennas are the most suitable for low-cost mass production. A slot antenna is a gap or aperture.

Micro-strip Patch antennas: -

A Micro-strip patch antenna is a thin conducting patch of any shape and size on one side of a dielectric substrate, the other side having a ground plane. Several feeding mechanism can be used for the micro-strip antenna and they offer the designer many parameters to optimize the antenna performance. The micro-strip antenna can be separated from the other circuitry to prevent distortion to the operation of the antenna and the circuit. Flexibility of the micro-strip antenna configurations was the main reason why these structures were chosen to be designed.

The antenna is assumed to operate at the basic resonance mode at which the electric field under the patch is uniform in the direction of the radiating edges and sinusoidal in the direction of the non radiating edges.

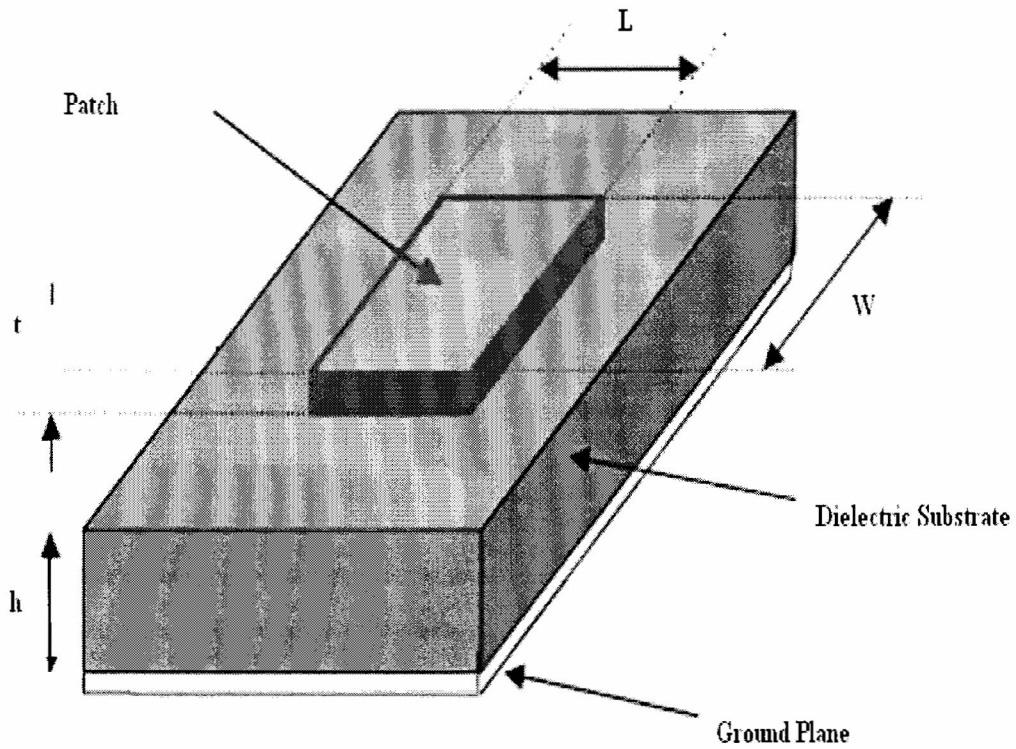


Figure 2.2: Structure of Micro-strip patch antenna.

The patch in the antenna is made of a conducting material Cu (Copper) or Au (Gold) and this can be of any shape Fig 2.3 , rectangular, circular, triangular, elliptical or some other shape as shown below. Rectangular shaped patch will be used in the present investigations. In this study a rectangular cavity has been considered in the antenna dielectric material. The dimensions of that cavity have been calculated in terms of length and width of the patch. There was no specification determined for the performance of the antenna and many parameters have been given as the designer to decide. The rectangular antenna element has been chosen which provides linear polarization.

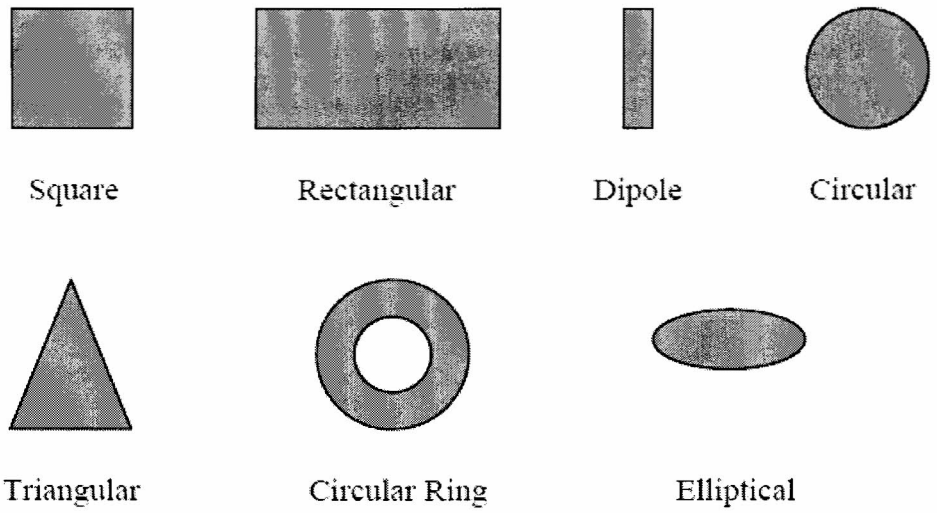


Figure 2.3: Common shapes of the patch antennas which are in use [13].

The basic antenna element is a thin conductor of length L and width W. It is deposited on a dielectric substrate with dielectric constant ε_r, height h and a ground plane. The rectangular patch antenna is designed so that it can operate at the specified resonance frequency. The length for the patch does depend on the height of the dielectric substrate. The length of the patch normally would be $0.333\lambda < L < 0.5\ \lambda$, where λ is the free space wavelength.

The physical length of the patch can be calculated by the simple formula from [14]

$$L_{eff} = L + 2\Delta L$$

L_{eff} = Effective length of the patch

L = Physical length of the patch

ΔL = Extension of length of the patch due to fringing fields

The height *h* of the dielectric substrate that supports the patch usually ranges between $0.003\ \lambda < h < 0.05\lambda$ Value of dielectric constant (ε_r) of the substrate is usually between 2.19 and 12.

The patch of the antenna is excited by feed which may be edge feed or a probe feed. When the patch is excited by feed, a charge distribution is established between the ground plane and the underneath of the patch. The underneath of the patch is charged positive and the ground plane is charged negative after excitation. The attractive forces are setup between

the planes i.e., patch underneath and the ground plane. The patch antennas radiate in the first case due to the fringing fields between the underneath of the patch and the ground plane.

These patch antennas are narrow band devices with a bandwidth ~ 10% of λ, and also having poor radiation efficiency. A good performance from the patch antenna can be expected with a thick dielectric substrate of low dielectric constant as this gives better efficiency, larger bandwidth and better radiation [07]. But these types of antennas are larger in size.

Gap in Existing Research

- When a patch antenna is fabricated, size of the fabricated resonance patch may be slightly different from its designed value due to tolerances in the fabrication operation. This will alter the resonance frequency.. There is no formula existing that relates the resonance frequency with dimensions of the cavity. To overcome this problem, this research proposal presents a new method for fine tuning of resonance frequency by using Dielectric Constant Engineering(inserting cavity in dielectric layer)

Methodology:-

Following steps will be implemented:-

Phase 1: Literature Survey

A detailed literature survey will be carried out to understand the theory of dielectric constant engineering, it is necessary to be equipped with the basic knowledge of effective dielectric constant. Since the effective dielectric constant provides some important properties of MS antenna like characteristic impedance, resonance frequency etc, so it can be used as a key parameter of any research related to MS antenna.

Continuous literature survey will be carried out to collect the information required during various stages of the proposed research. The source of this literature survey will be various available journals like, IEEE, IETE, Journal of wireless communication, e-books, internet sites and e-journals source .

Phase 2: Designing of micro strip antenna without cavity

A micro-strip patch antenna will be designed for operation at 2.4 GHz. Standard formulae and standard design procedure will be used for drawing the 3D structure of basic antenna. The dielectric substrate will be considered to be a four layer structure. Because of easy availability FR4 epoxy will be selected as the dielectric material.

HFSS software will be used to construct the 3D model and to simulate antenna characteristics. The resonance frequency of the antenna without cavity will be determined from simulations. Then, the antenna will be designed at 1.6 GHz, 1.8 GHz with different dielectric constant 4.4, 2.2 and 3.

Phase 3: Designing of micro strip antenna with cavity

By inserting air cavity in dielectric layer just below the patch and varying its dimensions (length and width), keeping one dimension parameter as a constant and another as a variable, different values of resonance frequency will be obtained for all above antennas.

Phase 4: Analysis of Results

A Graph between the resonance frequency ratios to area ratios will be plotted. The relation between them is given by the equation of the curve. A mathematical formula that relates the resonance frequency with dimensions of the cavity is derived by considering the patch – dielectric substrate – ground structure as series- parallel combination of capacitors.

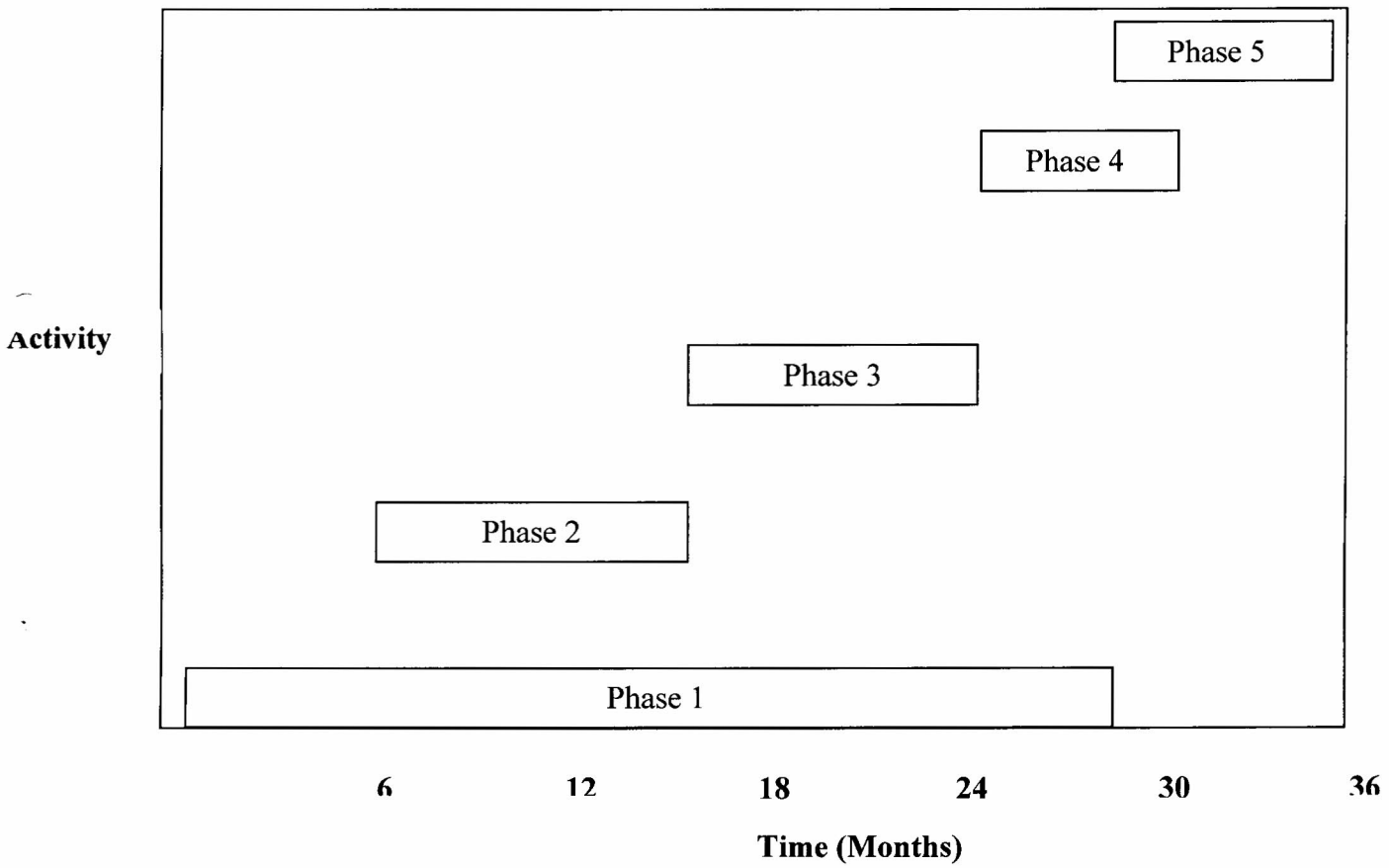
Phase 5: Conclusion and Thesis writing

In this phase, all the experimental and theoretical work carried out in different phases will be documented in the form of thesis.

Work Plan

The work-plan for the above-mentioned seven activities is shown in figure.

Figure: WORK PLAN



DIELECTRIC CONSTANT ENGINEERING:

THE DESIGN

The term "Dielectric Constant Engineering" means engineering (modifying) the dielectric constant of material to a new desired value. Dielectric Constant Engineering (DCE) will be achieve by (i) modifying the physical structure of the material and, (ii) incorporating a second material in the original material. For #(i) A three dimensional solid materials will be removed from the dielectric material just below the patch. This will be termed as cutting a 'CAVITY'. For #(ii) air will be filled in the cavity. Multilayer dielectric will be chosen due to ease in modification in physical structure of the material. The term Air- cavity refers to the space created by removal of material from that layer.

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Design of the rectangular patch antenna

Design Calculation:-

Throughout this work some parameters have been given specific values (unless otherwise stated).

These are:

- **Dielectric Constant of the Substrate (ε_r):**

The dielectric material used for the Micro-strip Patch Antenna is FR4 epoxy with $\varepsilon_r = 4.4$, as this is most popular material used due to low cost.

- **Frequency of Operation (f_0):**

In this design, the frequency of operation for the Patch antenna will be selected as 2.4 GHz.

- **Height of the dielectric substrate (h): 1.6 *4 = 6.4 mm**

The antenna is being excited with the line feed located at distance *dy*, from the centre of the patch towards the y- direction.

The antenna is being excited with a micro-strip line. For impedance matching an inset will be cut in the patch. Size of the inset will be optimized by HFSS. Micro-strip feed line will be

extended into the inset by an amount equal to the length of the inset. At the end of the inset the feed line is joined with the patch.

Table Design parameter specifications of the Micro-strip Antenna

Type of the antenna	Rectangular Patch antenna
Dielectric Constant of the substrate	4.4 of all the Four layers
Operating frequency	2.4 GHz
Height of the substrate	1.6 mm of one layer (6.4 mm total)
Feeding method	Micro strip Line Feed

1) Calculation of Width (**W**):

By the formula:

$$W = \frac{c}{2f_0}\sqrt{\frac{2}{\varepsilon r+1}} \quad \text{..... (3.1)}$$

2) Calculation of Effective dielectric constant (ε_{reff}):

From the equation

$$\varepsilon_{reff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}[1 + 12\,h/W]\text{^}(-1/2) \text{ ..... (3.2)}$$

3) Calculation of effective length:

From the equation

$$L_{eff} = \frac{c}{2f_r}\frac{1}{\sqrt{\varepsilon_{eff}}} \text{ ..... (3.3)}$$

4) Calculation of the length extension (ΔL) :

From the equation

$$\Delta L = \frac{0.412h(\varepsilon_{eff}+0.3)\left(\frac{W}{h}+.264\right)}{(\varepsilon_{eff}-0.258)\left(\frac{W}{h}+0.8\right)} \ldots\ldots\ldots\ldots\ldots\ldots\ldots (3.4)$$

5) Calculation of the length of the patch (***L***)**:**

By the equation

$$L_{eff} = L + 2\Delta L \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3.5)$$

6) The feed place determination.

The feed line will be designed to have a characteristic impedance of 50 ohm. For impedance matching an inset to be cut in the patch and the feed line has to be joined with the patch at the end of this inset. Length of this inset will be optimized by using parametric analysis tool of HFSS.

3.1.2 Antenna design procedure:-

The design formulae for micro-strip antennas have been given above. The physical structure will be simulated by using the 3D electromagnetic simulator HFSS .

POSIBLE OUTCOMES

Dielectric constant engineering will be used for fine tuning resonance frequency of micro-strip antenna. Slight variation in effective dielectric constant will offset the effect of change in patch length. Effect of cavity size on shift in resonant frequency will be investigated. f/f_0 will be plotted against Area Ratio (AR) to generalize the findings. Area Ratio is the ratio of area of cavity to the area of the patch, f is the resonance frequency for a given cavity area and f_0 is its value without any cavity.. For all ε and all f/f_0 the curve will be described by the equation.

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